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Combined cycle versus one thousand diesel power plants: pollutant emissions, ecological efficiency and economic analysis

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Abstract

The increase in the use of natural gas in Brazil has stimulated public and private sectors to analyse the possibility of using combined cycle systems for generation of electrical energy. Gas turbine combined cycle power plants are becoming increasingly common due to their high efficiency, short lead times, and ability to meet environmental standards. Power is produced in a generator linked directly to the gas turbine. The gas turbine exhaust gases are sent to a heat recovery steam generator to produce superheated steam that can be used in a steam turbine to produce additional power. In this paper a comparative study between a 1000 MW combined cycle power plant and 1000 kW diesel power plant is presented. In first step, the energetic situation in Brazil, the needs of the electric sector modification and the needs of demand management and integrated means planning are clarified. In another step the characteristics of large and small thermoelectric power plants that use natural gas and diesel fuel, respectively, are presented. The ecological efficiency levels of each type of power plant is considered in the discussion, presenting the emissions of particulate material, sulphur dioxide (SO_2), carbon dioxide (CO_2) and nitrogen oxides (NO_x).

Keywords: Natural gas; Diesel oil; Ecological efficiency

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1. Introduction

Since 1995, the start of the Brazilian electricity sector privatization, the electricity supply has not accompanied the growth of demand. As consequence, the thermal power generation is an important part in this scenario because of the short time of power plant implantation, the low investment cost and the low pollutants generation (natural gas is the utilised fuel).

The difference between electricity consumption and supply creates a complicated situation when analysed by several factors. The energy industry in Brazil needs restructuring because of its strong dependence in hydroelectricity, which is highly dependent on the climatic variations. Different ways for energy generation capable to assist the demand and the economical growth can be developed. Without this transformation, it is difficult to foresee the structural and operational characteristics of the electricity market for the coming years. The electricity production depends on the power plants that should be removed, restored, restructured and built along the years.

According to [1] the electricity generation in Brazil occurs mainly with hydroelectric power plants. This alternative represents 91.4% of the installed power generation capacity in Brazil in December 1998. The nation's inventoried and estimated hydropower potential reaches nearly 270 GW, today, which is equivalent to 1130 TW h/year of firm energy. The situation of the Brazilian energy sector was relatively balanced along the 1990s, but due to restrictions of investments in the sector, an energy crisis started in 2001. The immediate diversification of Brazilian power generation capacity is necessary either through the immediate incorporation of thermoelectric power plants using natural gas or through the introduction of cogeneration systems and the incorporation of renewable energies. In this context, and also for the purpose of electricity rationalisation and conservation, the electric power supply will increase in the country, attempting to assist the demand satisfactorily. In this way, the economical growth of the country can be maintained.

Those alternatives for increase of the electricity supply in Brazil should be incorporated seeking at least a self-maintainable or maintainable development, taking into account the associated costs of the energy generation and the limits of emissions established for the Brazilian Legislation and for the World Health Organisation. The Brazilian people cannot pay a highly expensive price for the electricity because they do not have

appropriate income for that. In 2001, there was an average 20% increase in electricity prices.

Reforms in the electricity sector have been planned mainly to reduce government investment in power plant construction, the risk of power shortages, and cut cost by introducing competition in electricity generation [2].

The Brazilian energy industry needs to change. The low price of natural gas (relatively to the other fuels), substantial improvements in gas turbine efficiency (including technological improvements in pollutant emissions), and the public contrary feeling to the rational electricity use are some reasons for this change. In future the electricity generation will be guided by competitive forces instead of regulators and politicians. The decisions on when, where and how to build, to reactivate or to remove power plants will be taken by organised and enterprising society instead of regulators.

Historically, the system has been planning, building and operating power plants in order to minimise the cost of electricity for a very long time. In a competitive atmosphere and in the energy crisis, the rules of decision should be replaced by a rule that highlights the availability of power plant units, excluding the hydroelectric units that can be built in a short time near the consumption centres.

2. The Brazilian electricity system

The Brazilian electricity system is quite complex, with many unique features. It is a large system, with an installed generation capacity of 64 GW in 1999 and a forecast of 107 GW by 2009 [3]. Brazil consumed approximately 291 TW h of electricity in 1999. The main peculiarity is the generation mix, dominated by hydropower, which is responsible for over 90% of the electricity supply, as can be viewed in Table 1. The system is formed by two major interconnected sub-systems, the South–Southeastern–Central and the North–Northeastern, besides many small isolated systems in remote regions. The most important is the South–Southeastern–Central sub-system that supplies the most developed regions of the country and currently accounts for over 75% of the entire country demand [1].

Table 1
Electricity generation in Brazil [4]

(GWh)	1990	1991	1992	1993	1994	1995	1996	1997	1998
Total	222,820	234,366	241,731	251,973	260,041	278,622	291,244	307,986	321,588
Natural gas	666	743	390	388	479	560	973	1107	5806
Steam coal	2814	3430	3322	3123	3393	3926	4374	5588	4902
Diesel oil	1898	1929	2290	2113	2203	3096	3112	4187	5211
Residual fuel	2834	2894	3162	3168	3270	3415	5101	4418	4863
Oil									
Fuel wood	622	571	790	864	666	646	669	692	687
Cane bagasse	1794	1875	2066	2022	2348	2574	3593	4080	3979
Black liquor	1144	1357	1800	1672	2166	2195	2273	2420	2526
Other wastes	1690	1901	1443	1662	1516	1373	4106	1563	1947
Cooking gas	445	525	487	515	305	304	429	402	440
Other sources	256	273	881	936	970	1065	1115	1298	1226
Uranium	2237	1442	1759	442	55	2519	2429	3169	3265
Hydropower	206,707	217,782	223,342	235,066	242,704	253,928	265,769	279,064	291,371

The thermal power supplies the part of the electrical system during the dry season, and the remainder of the market in the isolated systems. Thermal power generation is also used for local services in case of power transmission constraints. A heavy reliance on hydropower also results in striking seasonal variation in power availability. Transmission grids thus play an important role in helping balance supply and demand.

The growth in electricity demand occurred much faster than the supply. The ratio of the growth in energy consumption and growth in the economy had an average increase of 1.5 between 1980 and 1998; in fact, there was a significant growth of electricity consumption in Brazil. In this context, if the energy supply does not follow the energy consumption, the prices associated with this commodity will be high, increasing the prices of goods.

The energy supply can be complemented by several ways, using different kinds of energy forms, such as natural gas, biomass, diesel oil, etc. If there is a supply increase, the price in R$/MW h will be lower (in 2005, 1 US$~2.7R$). The electricity tariff rose from 60 R $/MW h in 1990 to 150 R$/MW h in 2000. At the same time, the deficit risk tripled.

As mentioned earlier, the electricity generation in Brazil is hydroelectricity-based and this alternative accounts for 91.4%. Therefore, the electricity system is dependent on the rainy season. The rainy season in Brazil occurs between December and April and the dry season occurs between May and November. In the last 5 years, due to the Brazilian economical growth associated to the lack of investment in the electricity sector and rain shortage at the end of 2000 and beginning of 2001, there was a considerable reduction in the water levels in the dams in Southeast and Northeast.

The power plant capacity factor (CF) (Eq. (1)) represents the behaviour of the electricity production

$$\mathrm{CF} = \frac{E_\mathrm{p}}{C_\mathrm{inst} \times \mathrm{t}},$$

where t is time ($\mathrm{t} = 8760\,\mathrm{h}$), $\mathrm{E_p}$ is the produced electricity and $\mathrm{C_{inst}}$ is the installed capacity.

Table 2 shows the electricity produced (Ep) and the installed capacity ($\mathrm{C_{inst}}$) for the hydroelectric power plants along the 1990s [4]. In this table, it is possible to verify the power production increase by hydroelectric power plants.

In the case of Brazil, the particular interest is how to adequately adapt the power generation sector to deal simultaneously with the supply of the country's fastest growing component of energy demand, and issues affecting domestic policies. Current reforms in

Table 2
Capacity factor of Brazilian hydroelectric system [4]

Year	Ep(GW h)	Cinst(GW)	CF(%)
1990	203,597	45.6	51.0
1991	214,609	46.6	52.6
1992	220,583	47.7	52.8
1993	231,695	48.6	54.4
1994	239,467	49.9	54.8
1995	250,456	51.4	55.7
1996	261,445	53.1	56.2
1997	274,586	54.9	57.1
1998	286,358	56.8	57.6
1999	287,043	59.0	55.5

the sector have been planned mainly to reduce government investments in power plant construction, the risk of power shortages, and cut cost by introducing competition in electricity generation [1].

3. Combined-cycle thermoelectric power plant

The combined-cycle thermoelectric power plant using natural gas is one of different options to combat the energy crisis. This option has a high thermodynamic efficiency and produces low environmental impacts, when compared to traditional thermodynamic cycles.

The First Law of Thermodynamics states that it is impossible to convert all the heat in mechanical work. This fact drives an analysis to the choice of the best system based on the higher thermodynamic efficiency. The energy analysis shows that the largest energy losses are associated to the condenser (including the cooling towers).

The Second Law of Thermodynamics mentions that not all processes that satisfy the First Law of Thermodynamic are possible. Real processes must also satisfy the Second Law. In this case, the same combined cycle presents the combustion processes as of the largest exergy losses. This has been motivating several researchers and manufacturers to produce improvements in exergy analysis based on the Second Law of Thermodynamics according to which complete transformation of heat into work is not possible [5]. Exergy can be defined as the maximum obtainable work from a given form of energy using environmental parameters as the reference state of the combustion systems looking for the maximum qualitative use of these equipments in the thermodynamic cycle.

4. Environmental policy in Brazil

According to the Brazilian legislation (Resolution 01/86 of the Environment National Advisory Board—CONAMA), the environmental impact is "…any of physical, chemical and biological properties alteration of the environment caused by any form, matter or energy resulting from the human activities that direct or indirectly affect:

I the health and the safety of the population;
II the social and economical activities;
III the Biota;
IV the aesthetic and sanitary conditions of the environment; and
V the quality of the environmental resources.". In the legislation of Brazil, there is the need for public audience to license new large power plants, which must present a Study of Environmental Impact (EIA) and a Report of Environmental Impact (RIMA).

5. Ecological impact of thermopower plants

In general, thermopower plants operated with coal and other hydrocarbons generate the biggest problem of the environment pollution. Combustion gases contain, almost exclusively, harmful components, which affects the life of humans, animals, and plants directly. Indirectly, it has negative effects as a result of the components CO_2 and NO_x which strongly contribute to the so-called greenhouse effect. The most important harmful

components of the combustion gases are carbon monooxide (CO), sulphur dioxide(SO_2), and the nitrous oxides (NO and NO2, generally denoted as NO_x) resulting from the use of any type of fuel, as well as the solid particles (ash) resulting from the use of any solid fuel, with less resulting from the use of oil. Also, there are some other harmful components in the combustion gases, for example, the heavy metals, the dioxins, etc., which, because of the very small concentration, get disregarded in all analyses of the ecological impact of thermopower plants, today. The other components mentioned above are considered more important because of their large quantity of emissions into the atmosphere [6].

The burning process produces nitrogen oxides (NO_x) where more than 95% are NO, the remainder being NO_2. In the atmosphere, because of the combination of NO with oxygen under the influence of ultraviolet rays, NO is transformed into NO_2, and this, either in this form or in the form of N_2O, is very harmful to living organisms, directly. Also, N_2O has a greater influence, about 200–300 times more than CO_2, in the greenhouse effect [7].

Presently, to analyse a thermopower plant from the point of view of atmospheric pollution resulting from burning fuels (combustion gases), the emission of each of the harmful gases, CO_2, SO_2, NO_x, is considered and the concentration of each one of them is compared with the limits of the existent imposed norms individually. With this methodology to analyse from the ecological point of view, a thermopower plant with high efficiency (with cogeneration and/or combined cycle) for which the values of the concentrations of harmful gas emissions exceed the imposed limits could be better regarding the ecological aspect than a thermopower plant where the corresponding emissions satisfy the imposed norms, but the efficiency is much lower (thermopower plant with Rankine cycle with steam turbine with condensation) [6].

According to [6] the ecological efficiency parameter (3) for steam cycles using coal was used. This parameter [9] was extended to combined cycle plants using natural gas, internal combustion engines and conventional and advanced cycles using biomass as fuel.

The work of this paper uses the ecological efficiency parameter (3) for combined cycle thermopower plant using natural gas/diesel and diesel engine. For the emissions of CO_2, SO_2, and particulate matter, the international air quality standards are considerd as reference. The ecological efficiency (3) evaluates, in an integral way, the environmental impacts caused by emissions released by thermopower plants. The evaluation considered the combustion of 1 kg of fuel, not the quantity of gas released from a thermopower plant per unit of useful energy generated as emission standards [8].

6. Methodology for the calculation of ecologic efficiency

As a reference during the analysis, the highest permissible concentrations of toxic substances in the air are considered and these values are presented in Table 3 [10].

Table 3
World health organization air quality standards [10]

Gas denomination	Average concentration in 1 h average(μg/m^3)
No_x	200
So_x	125

According to CONAMA's (National Environment Council) Resolution no. 3, 28 June 1990, the value permissible for particulate material (PM) concentration, is 150 mg/m^3. Some countries have been implementing taxes on carbon, which penalize those who release high concentrations of CO_2 and encourage reductions establishing a maximum limit for its emission. Based on these standards and considering the maximal permissible CO_2 concentration, which is 10,000 mg/m^3 [11], one can find the coefficients for the calculation of the concentration of a hypothetical pollutant called 'Equivalent Carbon Dioxide' (CO_2)e, According to [11], for calculation of this coefficient one has to divide the values of the CO_2 maximal permissible concentration by the air quality standards corresponding to NO_x, SO_x and PM in 1 h average. Thus, the expression for (CO_2)e is:

$$(CO_2)_e = (CO_2) + 80(SO_2) + 50(NO_x) + 67(PM).$$

In Eq. (2), the sulphur dioxide equivalent in (CO2) is (SO2)e = 80 (SO_2), the nitrogen oxide equivalent in (CO_2) is (NO_x)e = 50 (NO_x) and the particulate matter equivalent in (CO_2) is $(PM)_e = 67$ (PM). The best fuel from the ecological point of view is the one that produces the minimum quantity of equivalent carbondioxide, $(CO_2)_e$, per unit of energy obtained by the burning of the same fuel. In order to quantify the reasonong, a 'pollution indicator' (Π_g) is defined [11]:

$$\Pi_g = \frac{(CO_2)_e}{Q_i},$$

where (CO_2)e in kg/kgf (kg/kg of fuel), Q_i in MJ/kg is the LHV (low heat value of the fuel) and Π_g in kg/MJ is pollution indicator, where kg is to the mass of $(CO_2)_e$.

7. Ecological efficiency

Ecological efficiency is an indicator that allows the evaluation of the environment impacts of the gaseous emissions released by a thermal power plant by using the comparison of the polluting emissions hypothetically integrated (CO_2 equivalent emissions that depend on the fuel composition, on the technology used and on the efficiency of pollution control systems) with the air quality standards. The conversion is also considered as a determining factor over the specific emissions, express in fractional number. According to [11], the ecological efficiency is calculated by:

$$\varepsilon = \left[\frac{0.204}{\eta + \Pi_g}\ 1\text{n}(135 - \Pi_g)\right]^{0.5},$$

where ε integrates the aspects that define the intensity of the environment impact of thermal power plant in one coefficient: the fuel composition, the combustion technology, in the pollution indicator) and the conversion efficiency.

The values of ε are directly proportional to the plant's efficiency and inversely proportional to the values of Π_g; also it varies between 0 and 1, similarly to the thermal plant's efficiency. Ecological point of view, $\varepsilon = 0$ is considered to be an unsatisfactory situation, but $\varepsilon = 1$ indicates the ideal situation [11].

8. Natural gas and diesel oil

Brazil's natural gas production and consumption rose steadily throughout the 1990s, with imports starting in 1999. Natural gas reserves as of January 2001 stood at about 232 billion cubic meters, the fourth-largest in South America, behind Venezuela, Argentina, and Peru. Brazilian natural gas consumption is expected to rise in the coming decade as the country works to become self-supporting in the oil sector and to lessen its dependence on hydropower. Much of this increase is expected to be fuelled by imports, although Brazilian discoveries of gas reserves could mitigate the need for dramatic increases in natural gas imports (Table 4).

According to COMGAS, the largest gas distributing company of the state of São Paulo, natural gas is distributed in the state of São Paulo by a pipeline about 2000 km long. For expansion of the commercialisation and distribution of natural gas in the state of São Paulo, which today presents 3.0 million N m^3/day of Brazilian gas and a complement of 8.1 million N m^3/day of Bolivian gas, by 2006, it is necessary to construct 1400 km of additional pipelines, with investments of about US$320 million.

The natural gas, in normal conditions of temperature and pressure (0 8 °C, 25 8 °C, 101.3 kPa), has a specific mass of about 714 g/m^3. In this condition, the m3 is denoted by the symbol Nm3 (N means normal).

An agreement between Brazil and Bolivia, for the next 20 years, allows a supply increase of 8.0 million N m^3/day of natural gas in the first year and a gradual growth of 16.0 million N m^3/day in the eighth year, staying in that level until completion of the agreement period.

The composition of natural gas is presented in Table 5. Combustion of natural gas produces a reduced amount of pollutants when compared to other fossil fuels. As the natural gas is scentless, a small percentage of sulphur is added to the gas for gas leakage detection.

Table 4
Reserves, production and consumption of natural gas in Brazil [12]

Year	Reserves (10^6 Nm^3)	Production (10^6 Nm^3)	Consume (10^6 Nm^3)	R/P (ANOS)
1983	81,606.0	4013.2	1739.0	20.0
1984	83,892.0	4902.5	2024.0	17.1
1985	92,734.0	5467.1	2539.0	17.0
1986	95,834.0	5686.5	2958.0	16.9
1987	105,343.0	5780.7	3302.0	18.2
1988	108,900.0	6076.0	3324.0	17.9
1989	116,008.0	6105.0	3408.0	19.0
1990	114,570.0	6279.0	3414.0	18.2
1991	123,776.0	6597.0	3458.0	18.8
1992	136,400.0	6976.0	3695.0	19.6
1993	137,400.0	7355.0	4016.0	18.7
1994	146,476.0	7756.0	4263.0	18.9
1995	154,306.0	7955.0	4435.0	19.4
1996	157,704.0	9156.0	5094.0	17.2
1997	227,650.0	9825.0	5408.0	23.2
1998	227,650.0	10,788.05	7370	21.1

Table 5
Natural gas composition

Component	%Vol.	%Mass
CH_4	89.35	80.92
C_2H_6	8.03	13.64
C_3H_8	0.78	1.94
C_4H_{10}	0.07	0.23
C_5H_{12}	0.01	0.04
CO_2	0.48	1.20
N_2	1.28	2.03
Total	100.00	100.00

According to Petrobrás (Brazilian Oil Company), the company produces 85% of the diesel fuel sold in the country. The remaining of the Brazilian market is assisted with imported products bought by Petrobrás.

The demand of diesel fuel in Brazil is high when compared to the other countries. In Brazil, the diesel market represents about 36% of the processed oil barrel, a quite superior number compared to other countries (USA: 18%; Japan: 25%). The Brazilian diesel consumption is attributed to the transport sector. This sector accounts for about 80% of the market.

A serious problem of the diesel is its high percentage of sulphur and it becomes worse when the high cost of the sulphur elimination in the diesel is considered. Besides, the Brazilian oil is very rich in sulphur, except for that found in the Bahia basin.

Petrobrás has implanted the Program of Evolution of the Diesel Quality to search a better performance of the engines and reduce the atmospheric emissions. For this, it will be investing about 1.2 billion dollars in refineries until 2004. The Program represented, in 1998, a reduction of about 240,000 ton of sulphur compounds in the atmosphere. Besides, the reduction in the emissions of sulphur compounds, the evolution in the diesel quality provides better performance of the engines, smoke and scents reduction. Since January 1998, the maximum percentage of sulphur in the national diesel fuel has been 0.5%.

9. Comparison between pollutant emissions

Environmental problems span a continuously growing range of pollutants, hazards and ecosystem degradation over wide areas. Problems with energy supply and use are related not only to global warming, but also to environmental concerns such as air pollution, acid precipitation, ozone depletion, forest destruction, and emission of radioactive substances. These issues must be taken into consideration simultaneously if mankind is to achieve a bright energy future with minimal environmental impacts [13].

This study shows a comparison between the emissions of particulate material, sulphur dioxide (SO_2) and nitrogen oxides (NO_x) of a large thermoelectric power plant with a set of 1000 small diesel units.

A natural gas power plant produces 240 kg of particulate material per million cubic meters of fuel. As the natural gas has a specific mass of 714 g/m^3, the power plant produces approximately 336 mg of particulate material/kg of natural gas burned. For a diesel engine, the emission factor of particulate material is 13.2 kg/m^3 of fuel. As the diesel has a

Table 6
Results of pollutant emissions comparison between a natural gas mega plant and 1000 diesel small units

	Diesel	Natural gas	Diesel/natural gas
(A) pollutation emission (mg/kWh)			
$(CO_2)_e$	424,019	200,139	2.1
Particulate material	1282.42	24.28	52.8 times
SO_2	826.45	–	–
NO_X	233.02	61.87	3.8 times
CO_2	260,330	195,418	1.3 times
Total (mg/kWh)	262.672	195,504	1.3 times
Ecological efficiency (%)	91.2	95.6	–
(B) Pollutants emission (kg/kg of fuel)			
$(CO_2)_e$	5.06	2.77	1.8
Particulate material	$15,300 \times 10^{-6}$	336×10^{-6}	45.5 times
SO_2	9860×10^{-6}	–	–
NO_X	2780×10^{-6}	856×10^{-6}	3.2 times
CO_2	3.1059	2.7038	1.1 times
Total (kg/kg of fuel)	3.1338	2.7050	1.2 times
Ecological efficiency (%)	91.2	95.6	–

specific mass of 864 kg/m^3, the diesel engine produces 15,300 mg of particulate material/kg of diesel.

Natural gas has a very low percentage of sulphur and this implies in a very low emission rate of SO_2. For diesel engine, the emission factor of SO_2 is 17.04 kg/m^3 for each 1% of sulphur in the diesel composition. Taking into account a sulphur percentage of 0.5% in the diesel composition (according to Petrobra′s), the emission rate of SO_2 will be about 9860 mg/kg of diesel burned.

For a modern thermopower plant using natural gas, a maximum of 15 ppmv of NO_x generated (in dry base), corrected for 12% Oxygen can be assumed [1]. Currently, there are gas turbines producing only 6 ppmv of NO_x in the combustion gases. For 15 ppmv, will be produced 856 mg of NO_x/kg of natural gas. On the other hand, a diesel engine generates 2.4 kg of NO_x/m^3 of fuel or 2780 mg of NO_x/kg of diesel.

For a thermopower plant using natural gas, 27,038 × 102 mg of CO^2/kg of natural gas will be produced. On the other hand, a diesel engine generates 31,059 × 102 mg of CO^2/kg of diesel.

Taking the electrical efficiencies of a diesel engine (26%) and of a combined-cycle thermopower plant (at least 54%) into account, and the low heating value of the natural gas and diesel (49,810 and 42,950 kJ/kg, respectively), it is possible to calculate the pollutant amounts expected for electric power produced (kW h) in both systems. The results are summarised in Table 6. From this table a great advantage in terms of atmospheric emissions of a mega plant using natural gas can be observed in relation to a set of small diesel units.

10. Comparison between the electricity production costs

The following study shows a comparison between the electricity production cost of a large thermoelectric power plant with a set of 1000 small diesel units.

Table 7
Results of economic alanalysis

	Electricity production cost
Combined-cycle thermoelectric power plant	0.053US$/kWh
Dieselunits	0.150US$/kWh
Ratio between costs of thermoelectric power plant and diesel units	1/3

The investment decisions are usually based on capital costs. The cost of electricity production is a function of the investment cost (capital cost plus installation cost), the operational cost (fuel cost plus labour cost) and maintenance cost. Besides, the electrical efficiency influences in the electricity production cost.

The cost of electricity production was performed taking the following considerations into account:

- Annual interest rate of 7% a year.
- Amortisation period of 10 years.
- Equivalent period of use of 7200 h/year.
- Investment cost on diesel engine of 800 US$/kW.
- Investment cost in combined-cycle thermoelectric power plant of 650 US$/kW.
- Lower heating value of the diesel of 42,950 kJ/kg.
- Lower heating value of the natural gas of 37,000 kJ/N m3.
- Cost of the diesel in energy base (LHV) of 0.0317 US$/kW h.
- Cost of the natural gas in energy base (LHV) of 0.0125 US$/kW h.
- Maintenance cost of diesel engines of 0.012 US$/kW h.
- Maintenance cost of combined-cycle thermopower plant of 0.017 US$/kW h.

The results of the economical analysis are shown in Table 7. From this table, a great advantage in terms of electricity production costs of the plant using natural gas can also be observed in relation to a set of 1000 small diesel units.

11. Conclusions

This paper made the comparative study between a 1000 MW combined cycle power plant and 1000 kW diesel power plants and permits the following conclusions:

- The energetic situation in Brazil, urgently need a modification in the electric sector.
- The demand management and integrated means planning, needs can be clarified.
- The levels of emissions of 1000 MW combined cycle power plant and 1000 kW diesel power plants are, respectively, 24.28 and 1282.42 mg/kW h or $336 \times 10K6$ and $15{,}300 \times 10K6$ kg/kg of fuel of particulate material; 0.00 and 826.45 mg/kW h or 0.00 and $9860 \times 10K6$ kg/kg of fuel of sulphur dioxide (SO_2), 195,418 and 260,330 mg/kW h or 2.70 and 3.11 kg/kg of fuel of carbon dioxide (CO_2); 61.87 and 233.02 mg/kW h or $856 \times 10K6$ and $2780 \times 10K6$ kg/kg of fuel of nitrogen oxides (NO_x). The total emission of a large thermo-power plant in comparison with one thousand diesel engine power plants are, 1.3 times based in mg/kW h or 1.2 times based in kg/kg of fuel.

- In terms of ecological efficiency, the characteristics of large and small thermoelectric power plants that use natural gas and diesel fuel, are, respectively, 95.6 and 91.2%.
- As economical conclusion, the electricity production cost in the 1000 MW combined cycle power plant and 1000 kW diesel power plants are, respectively, 0.053 and 0.150 US$/kW h.

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